Comprehensive analysis of the potential of introducing renewable energy to reduce GHG and SO_2 emissions in Chonqing city, China

Qian Zhou*, Takeshi Mizunoya, Helmut Yabar, Yoshiro Higano

Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan

1. Introduction

The access to a stable energy supply is a very important condition to achieve sustainable development. China has largely relied on the utilization of fossil fuels, especially coal, as a primary energy source to meet increasing demand for economic development. This situation has led to an inappropriate energy consumption structure. Furthermore, environmental degradation including acid rain associated with this unsustainable energy structure is becoming more prominent, with the rapid economic development. Renewable energy, an effective tool in reducing SO_2 and GHG emissions and in providing energy supply, has attracted increasing attention worldwide as clean energy resource (Dincer, 2000; Menegaki, 2008; Zheng, Zhang, Yu, & Lin, 2011). Chongqing is a typical area in this respect; almost all of its energy comes from fossil fuels particularly coal. The proportion of coal to the total energy utilization was 70 % in 2010 (Chongqing Municipal Bureau of Statistics, 2011). The reliance on coal for energy supply has caused environmental problems including acid rain and air pollution in addition to the rapid increase in GHG emissions. It is significant for Chongqing to introduce renewable energy technologies to improve the local energy structure while achieving the SO_2 and GHG emission targets set by the Chinese Central Government. Chongqing is located in Southwest China, where the distribution rate of economically exploitable hydro resources in China is 58.9 % (Huang & Yang, 2009). This means hydropower will be an important potential renewable energy contributing to energy structure transformation. Additionally in the "12th Five Year Plan", the Chongqing government plans to introduce wind power technologies to promote the wind power industry. In this process, evaluation of candidate renewable technologies is a significant step for government policy-makers to decide budget allocation, mitigation plans, energy and economic development. Consequently, the specific objectives of this study are to comprehensively analyze the impact of small-scale hydropower and wind power technologies to explore renewable energy potential in Chongqing and the feasibility of introducing these technologies. We chose the "Chongqing Siyangping 49.3 MW Wind Power Project" and the "9.6 MW Xiaohe Small Hydropower Project, China", registered CDM projects as reference for the potential of renewable energy introduction. “Renewable technologies” refers to these two kinds of technology projects in this paper.

Recently, many studies employing Input-Output models have been undertaken to comprehensively evaluate policies which act as a motivation to make optimal balance between economic development and environmental protection. Mizunoya and Higano (1999) simulated an optimal tax-subsidy to reduce air pollutant (CO_2, SO_2, NO_x) emissions in Japan. Li et al. (2012) analyzed the impact of a recycling tax on metal recycling and GHG emission. Sakurai et al. (2003) proposed an environmental tax rate to maximize GDP under restriction of GHG emission based on an I/O model. Li and Higano (2004) simulated the best environmental tax rate for policies to introduce renewable energies for emission reduction in China. Wang et al. (2012) investigated an environmental tax to develop biomass power technologies for GHG mitigation.

However, limited research has been undertaken to comprehensively evaluate the benefits of renewable energy technologies via a simulation model and later identify the feasibility of introducing them. In this study, we propose an integrated environmental management policy using a computer simulation that includes the introduction of renewable energy technologies to improve the air quality in Chongqing and minimize GHG emissions while achieving optimal economic development. Three sub-models (material flow balance model, socio-economic model and energy balance model) and one objective function, gross regional product (GRP), were included in the simulation. The paper also describes the methodology of the Input-Output model and puts forwards a comprehensively initial policy analysis.

2. Method

This paper focused on building a comprehensive simulation model system to forecast environmental improvement potential based on input-output table and balances simulating social, economic and environmental developments. The simulation model considered significant factors, such as GRP growth, energy consumption and the existing individual sub-sectorial policy targets.

This study utilized an optimization simulation model, comprising dynamic linear LINGO programming, to evaluate the impact of the renewable energy technologies on gas emission reduction along with optimized economic development in the research area. The comprehensive simulation model can precisely estimate the benefits that may result from social, economic, and environment policy decisions.

2.1 Scheme of the Simulation Model

The simulation model is composed of 3 sub-models (socio-economic model, air emission model and energy demand-supply model) and one objective function (Figure 1). Chongqing's social and economic activities provide the simulation base and reflect real social and economic development. Three economic agents (industry, household, government) were assumed in this research.

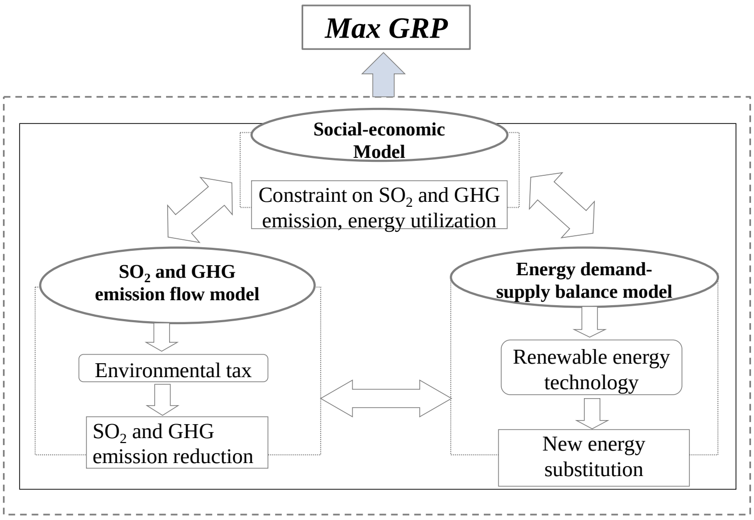

Figure 1. Model framework

There are four big industries in the model. Each industry contains several sectors. We calculated the input coefficients between economic agents based on "2010 Input-Output table of Chongqing".

2.2 Design of the Simulation Model

In the simulation model, the variables are divided into endogenous (*en*) and exogenous (*ex*). The exogenous parameters are calculated based on current data; the endogenous variables will be determined by the model structure. The research period is 11 years, from 2010 to 2020. The selection of the research period was based on the availability of specific government targets for both SO_2 and GHG emissions. The objective function of this simulation is to maximize GRP of the study area and it can be formulated as:

$$Max \sum_{t=1}^{11} \left(\frac{1}{1+\rho} \right)^{t-1} GRP(t) \qquad (\rho = 0.05) \tag{1}$$

$$GRP(t) = V_1 X_1(t) + V_2 X_2(t) + V_3 X_3(t) + V_4 X_4(t) \tag{2}$$

Where, *GRP (t)* is the gross regional product in term *t (en)*, $X_i(t)$ is the production of each industry *i* in term *t (en)* and ρ is the social discount rate. V_i is the value-added rate of industry *i (ex)*. The objective function is subject to the following constraints.

2.2.1 Balance of the Material Flows

In Formula 3, the left side represents the supply and the right side represents the demand. Usually, the supply is not lower than the demand. The input coefficient of production is calculated based on the 2010 input-output table of Chongqing.

$$X(t) \geq \sum_{j=1}^{4} A_{ij} X_j(t) + C_i^h(t) + \overline{C}_i^g + I_i(t) + \overline{E}_i - M_i(t) \qquad (i = 1 \ldots 4) \tag{3}$$

$X_i(t)$: commodity of each sector in industry *i* (*en*, column vector)

A_{ij}: input coefficients from industry *i* to industry *j* (*ex*, matrices)

$C_i^h(t)$: household consumption of each sector in industry *i* (*en*, column vector)

$\overline{C}_i^g$: government consumption in each sector in industry *i* (*ex*, column vector)

I_i: investment in each sector in industry *i* (*en*, column vector)

$\overline{E}_i(t)$: export of each sector in industry *i* (*ex*, column vector)

$M_i(t)$: import of commodity of each sector in industry *i* (*en*, column vector)

2.2.2 Energy Flow Balance

The energy supply in left side is not lower than the energy demand from industries, household consumption, export and import.

$$X_e(t) \geq \sum_{i=1}^{4} A_{ei} X_i(t) + C_e{}^h(t) + \overline{E}_e - M_e(t) \tag{4}$$

Where $X_e(t)$ is energy supply and A_{ei} is input coefficient

2.2.3 Value Balance

The left side of the formula is the income and the right side includes expenses. The income of each industry is equal to the expenses.

$$P_i(t)\tilde{X}_i(t) = P_1(t)A_{1i}\tilde{X}_i(t) + P_e(t)A_{ei}\tilde{X}_i(t) + P_3(t)A_{3i}\tilde{X}_i(t) + Y_i^h(t) + \delta_i\tilde{X}_i(t) + \tau_i\tilde{X}_i(t) \tag{5}$$

$P_i(t)$: price rates of each sector in industry *i* (*en*, row vector)

$Y_i^h(t)$: national income of each sector in industry *i* (*en*, row vector)

δ_i: depreciation rate of each sector in industry *i* (*ex*, row vector)

τ_i: indirect tax rate of each sector in industry *i* (*ex*, row vector)

References

Andrew, M. (2012). Non-greenhouse gas emissions from coal-fired power plants in China. Retrieved from http://www.iea-coal.org.uk/report/80571//82994/Non-greenhouse-gas-emissions-from-coal-fired-power-plants-in-China,-CCC-196

Chongqing Municipal Bureau of Statistics (2011). *Chongqing Statistical Yearbook.* Chongqing, Chongqing Bureau of Statistics.

Dincer, I. (2000). Renewable energy and sustainable development: a crucial review. *Renewable and Sustainable Energy Reviews, 4*(2), 157-175. http://dx.doi.org/10.1016/S1364-0321(99)00011-8

Dones, R., Heck, T., Bauer, C., Hirschberg, S., Bickel, P., Preiss, P., … De Vlieger, I. (2005). ExternE-Pol Externalities of Energy: Extension of Accounting Framework and Policy Applications. *Paul Scherer Institute.*

Eggleston, S., Buendia, L., & Miwa, K. (2006). *2006 IPCC guidelines for national greenhouse gas inventories [recurso electrónico]: industrial processes and product use,* Kanagawa, JP: Institute for Global Environmental Strategies.

Haines, A., Smith, K. R., Anderson, D., Epstein, P. R., McMichael, A. J., Roberts, I., … Woods, J. (2007). Policies for accelerating access to clean energy, improving health, advancing development, and mitigating climate change. *The Lancet*, *370*(9594), 1264-1281. http://dx.doi.org/10.1016/S0140-6736(07)61257-4

Huang, H., & Yan, Z. (2009). Present situation and future prospect of hydropower in China. *Renewable and Sustainable Energy Reviews, 13*(6), 1652-1656. http://dx.doi.org/10.1016/j.rser.2008.08.013

KPMG China. (2011). China’s 12th Five-Year Plan: Sustainability. Retrieved from http://www.kpmg.com/CN/en/IssuesAndInsights/ArticlesPublications/Documents/China-12th-Five-Year-Plan-Sustainability-201104-v2/

Li, B., & Higano, Y. (2004). Countermeasures against Global Warming in China-From the View of Point of Encouragement of Green Energy. *Studies in Regional Science, 34*(1), 117-138. http://dx.doi.org/10.2457/srs.34.117

Li, Y., Zou, S., Xu, F., Yabar, H. & Higano, Y. (2012). The Impact of Introducing Recycling Taxes on China’s Environmental Policy: Case Study on E-waste Recycling. *Journal of Sustainable Development*, *5*(4), 83. http://dx.doi.org/10.5539/jsd.v5n4p83

Matus, K., Nam, K.-M., Selin, N. E., Lamsal, L. N., Reilly, J. M., & Paltsev, S. (2012). Health damages from air pollution in China. *Global Environmental Change, 22*(1), 55-66. http://dx.doi.org/10.1016/j.gloenvcha.2011.08.006

Menegaki, A. (2008). Valuation for renewable energy: A comparative review. *Renewable and Sustainable Energy Reviews, 12*(9), 2422-2437. http://dx.doi.org/10.1016/j.rser.2007.06.003

Millman, A., Tang, D., & Perera, F. P. (2008). Air pollution threatens the health of children in China. *Pediatrics, 122*(3), 620-628. http://dx.doi.org/10.1542/peds.2007-3143

Mizunoya, T., & Higano, Y. (1999). Air Pollutants Emission Reduction and the Optimal Tax-Subsidy Policy for Japan. *Studies in Regional Science, 30*(3), 85-104. http://dx.doi.org/10.2457/srs.30.3_85

Pascal, M., Viso, A. C., Medina, S., Delmas, M. C., & Beaudeau, P. (2012). How can a climate change perspective be integrated into public health surveillance? *Public Health, 126*(8), 660-667. http://dx.doi.org/10.1016/j.puhe.2012.04.013

Sakurai, K., Kobayashi, S., Mizunoya, T., & Higano, Y. (2003). The Impact of Environmental Tax on the Japanese Economy as a Policy Measure for the Global Warming–An Analysis through Environmental Economic System Simulation. *Studies in Regional Science, 33*(3), 49-66. http://dx.doi.org/10.2457/srs.33.3_49

Wang, S., Xu, F., Xiang, N., Mizunoya, T., Yabar, H., Higano, Y., & Zhang, R. (2012). A Simulation Analysis of the Introduction of an Environmental Tax to Develop Biomass Power Technology in China. J*ournal of Sustainable Development, 6*(1), 19. http://dx.doi.org/10.5539/jsd.v6n1p19

Xu, Y., Williams, R. H., & Socolow, R. H. (2009). China's rapid deployment of SO_2 scrubbers. *Energy & environmental science, 2*(5), 459-465. http://dx.doi.org/10.1039/b901357c

Zhao, Y., Zhang, J., & Nielsen, C. (2012). The effects of recent control policies on trends in emissions of anthropogenic atmospheric pollutants and CO_2 in China. *Atmos. Chem. Phys. Discuss, 12*, 24985-25036. http://dx.doi.org/10.5194/acpd-12-24985-2012

Zheng, X., Zhang, L., Yu, Y., & Lin, S. (2011). On the Nexus of SO_2 and CO_2 emissions in China: the ancillary benefits of CO_2 emission reductions. *Regional Environmental Change, 11*(4), 883-891. http://dx.doi.org/10.1007/s10113-011-0227-8